High-Power Targets at J-PARC #2 - Neutrino & Hadron Facilities -

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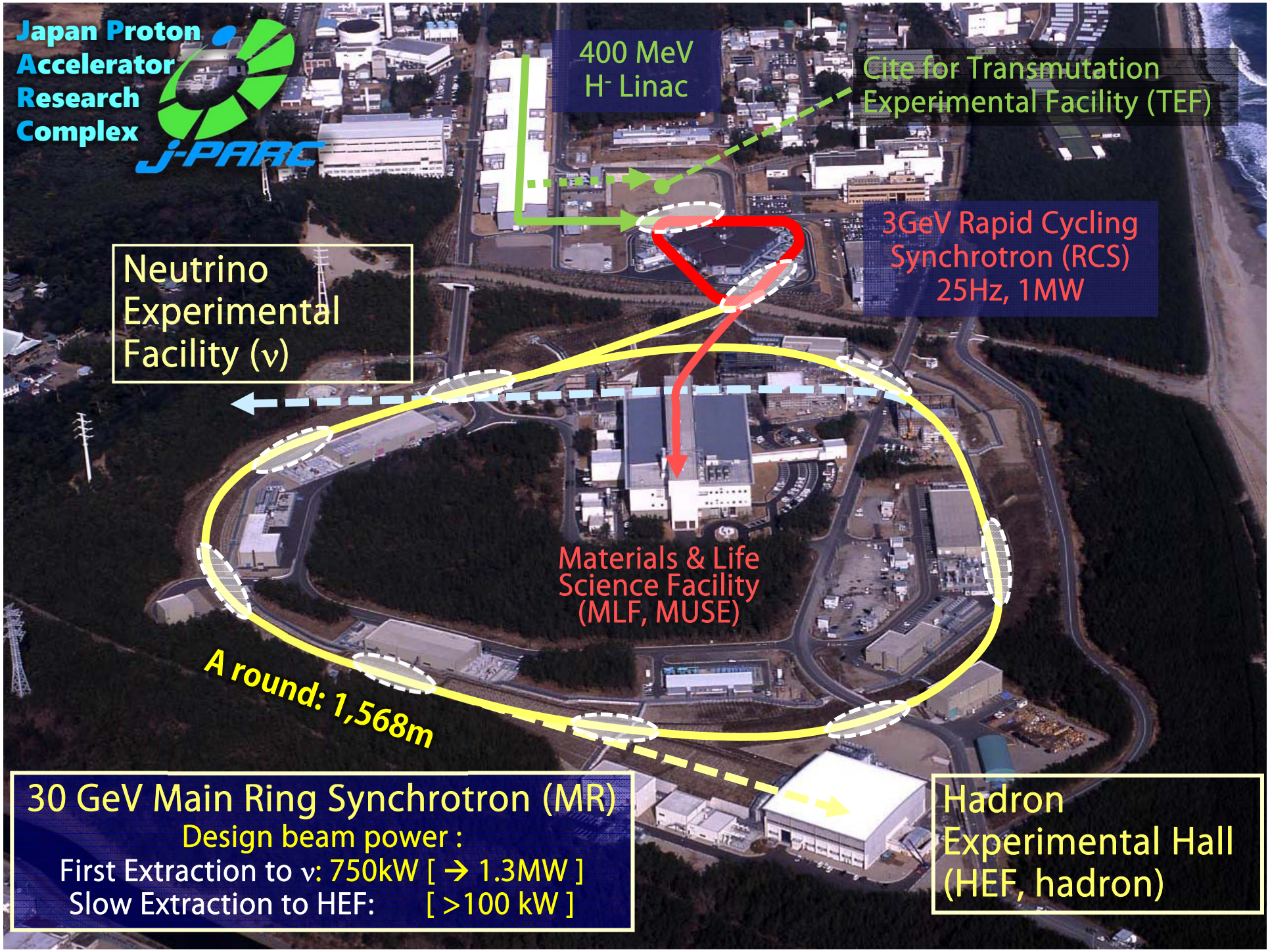
Rutherford Appleton Laboratory

* Hadron Experimental Facility Materials from
H. Takahashi (J-PARC/KEK)

Outline

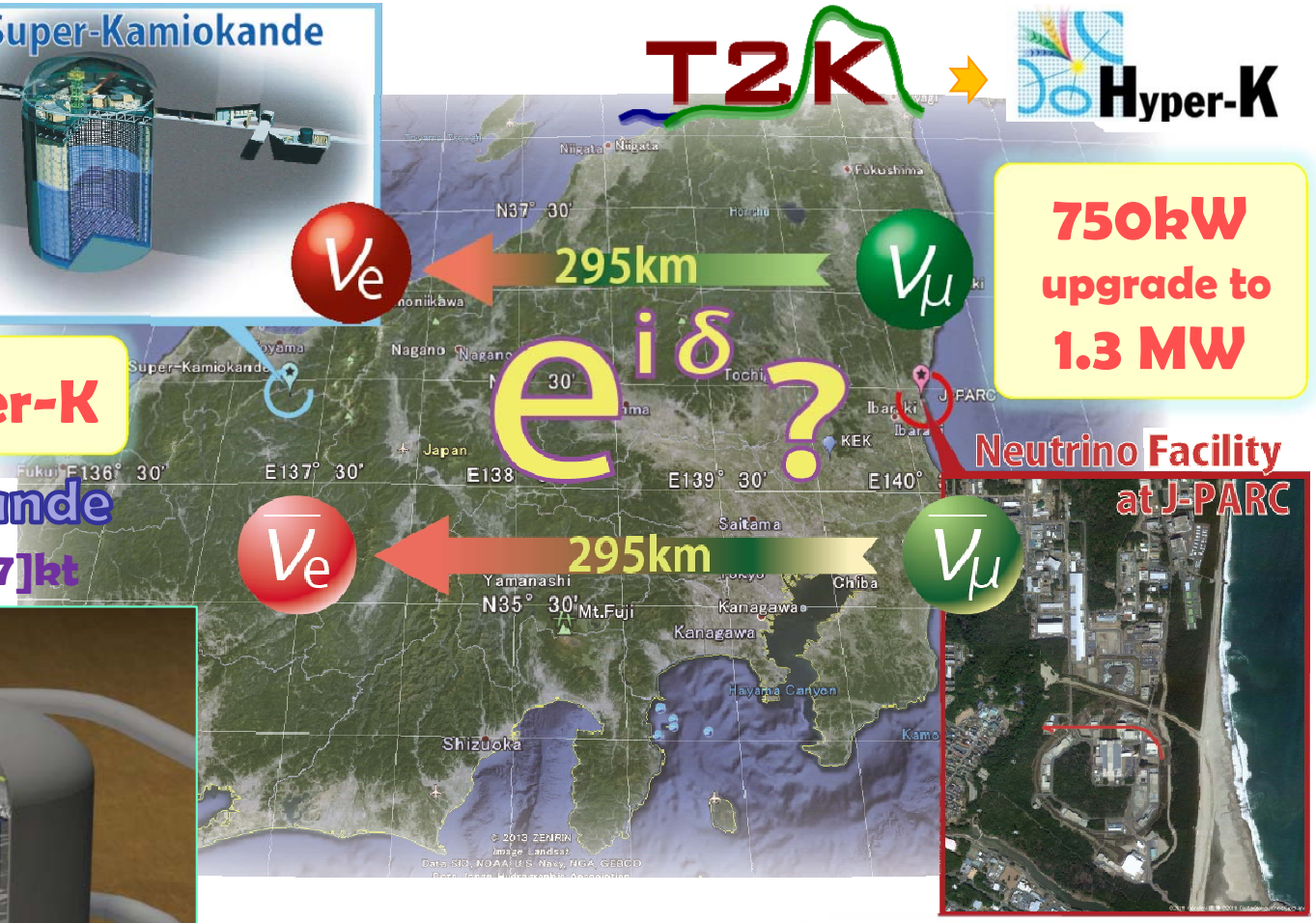
- Facilities Introduction
  - Neutrino experimental facility (J-PARC ν)
  - Hadron Experimental Facility (HEF)
  - Beam parameters, operational status and plan
- Hadron target
  - Current deign and upgrade, necessary R&Ds
- Neutrino target and window

J-PARC FACILITIES INTRODUCTION


Japan Proton Accelerator Research Complex
J-PARC
400 MeV H⁻ Linac
Cite for Transmutation Experimental Facility (TEF)
3GeV Rapid Cycling Synchrotron (RCS) 25Hz, 1MW
Neutrino Experimental Facility (ν)
Materials & Life Science Facility (MLF, MUSE)
A round: 1,568m
30 GeV Main Ring Synchrotron (MR)
Design beam power :
First Extraction to ν: 750kW [→ 1.3MW]
Slow Extraction to HEF: [>100 kW]
Hadron Experimental Hall (HEF, hadron)

Neutrino Experimental Facility at J-PARC

39mϕ x 41mH
Total[Fiducial]
Volume
= 50[22.5]kt

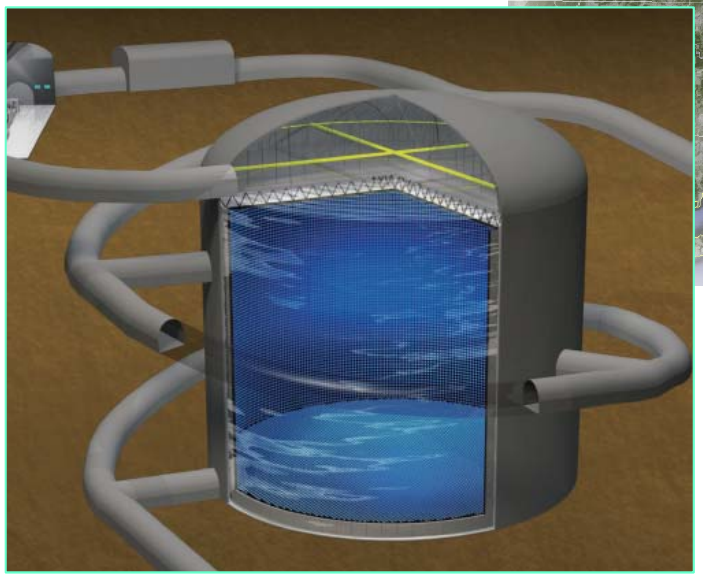


750kW
upgrade to
1.3 MW

x ~10 of Super-K

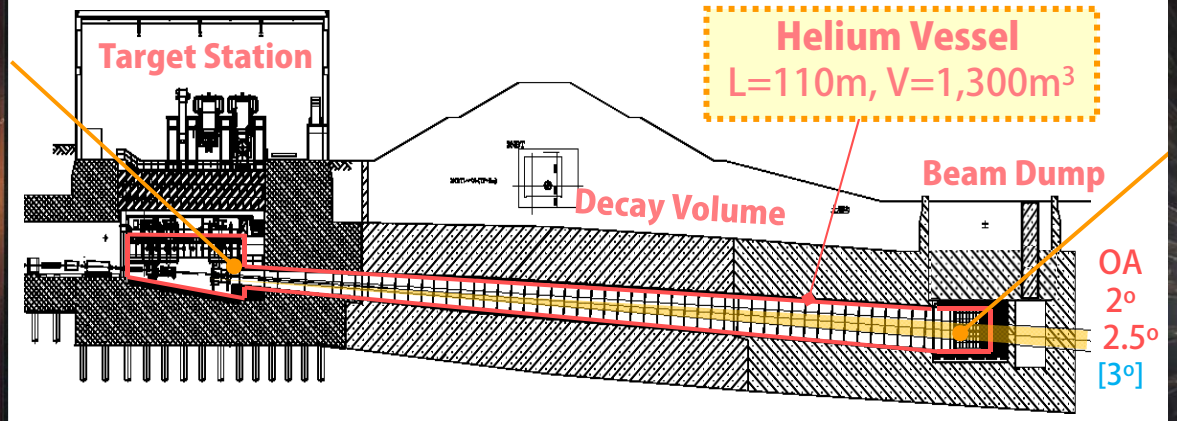
Hyper-Kamiokande

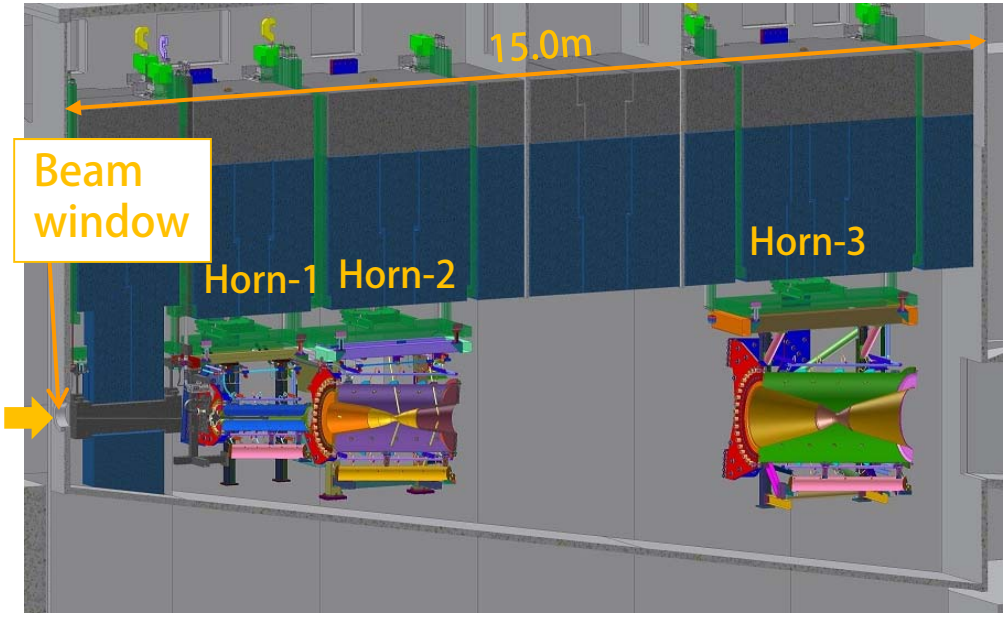
74mϕ x 60mH = 258[187]kt

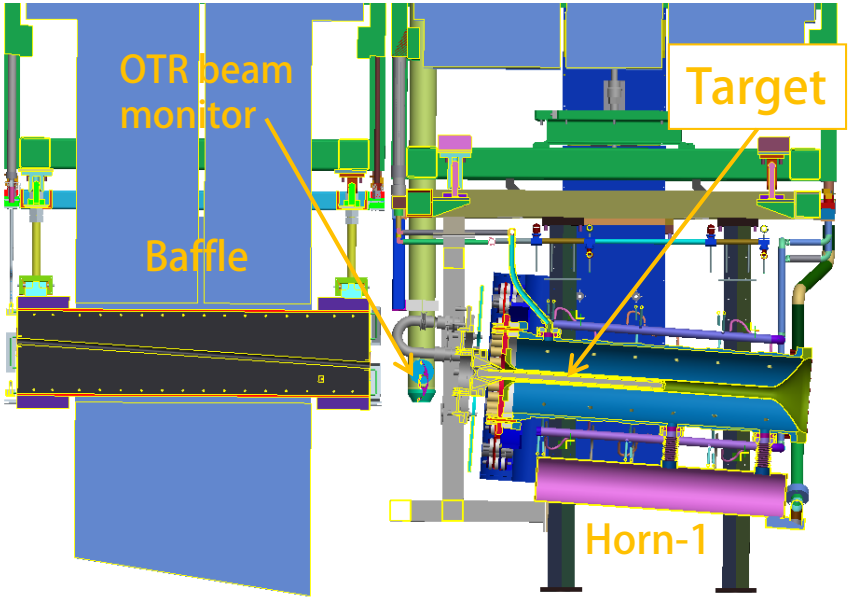


Exploring CPV in
Lepton Sector

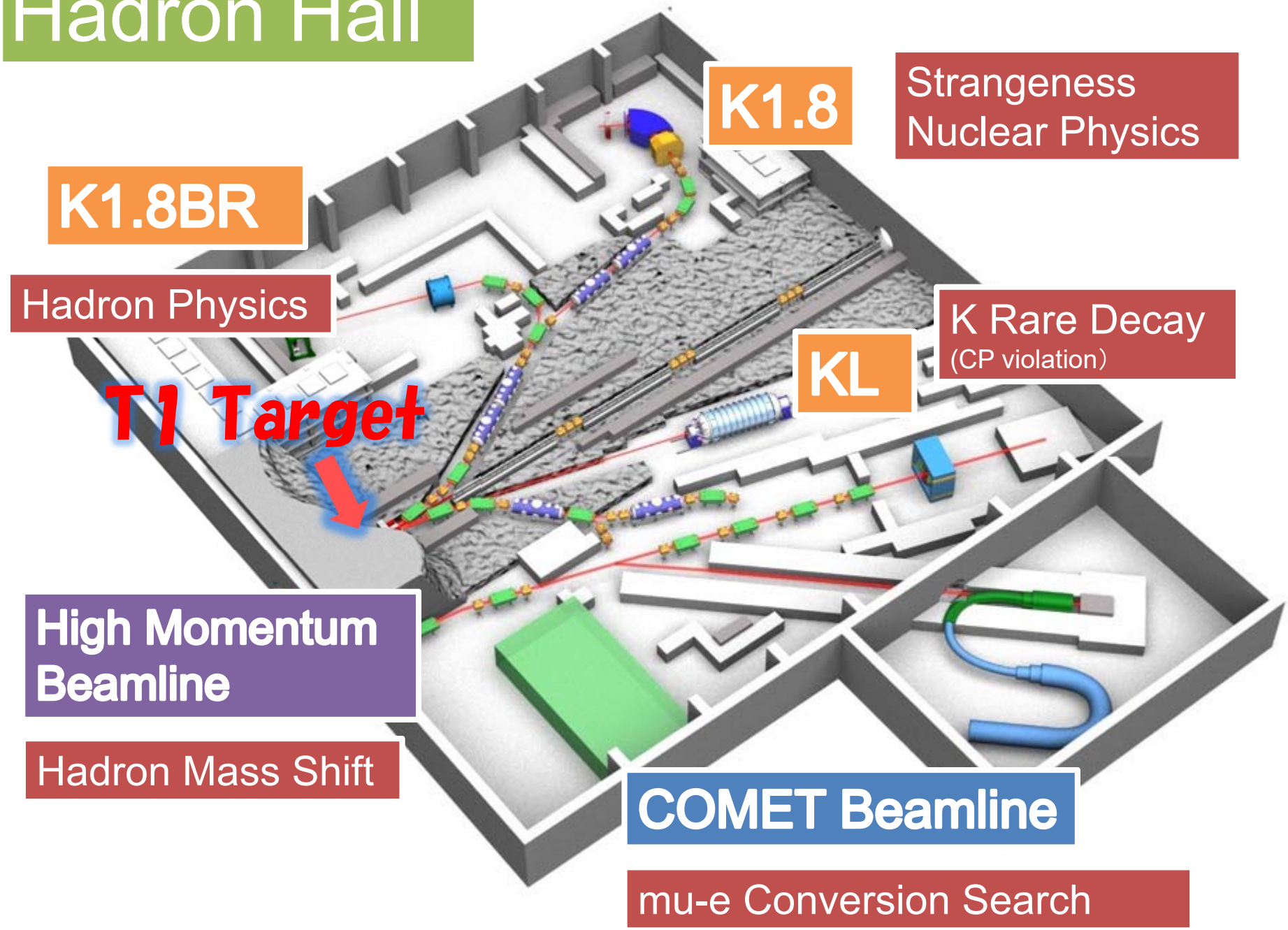
Neutrino Secondary Beam-line



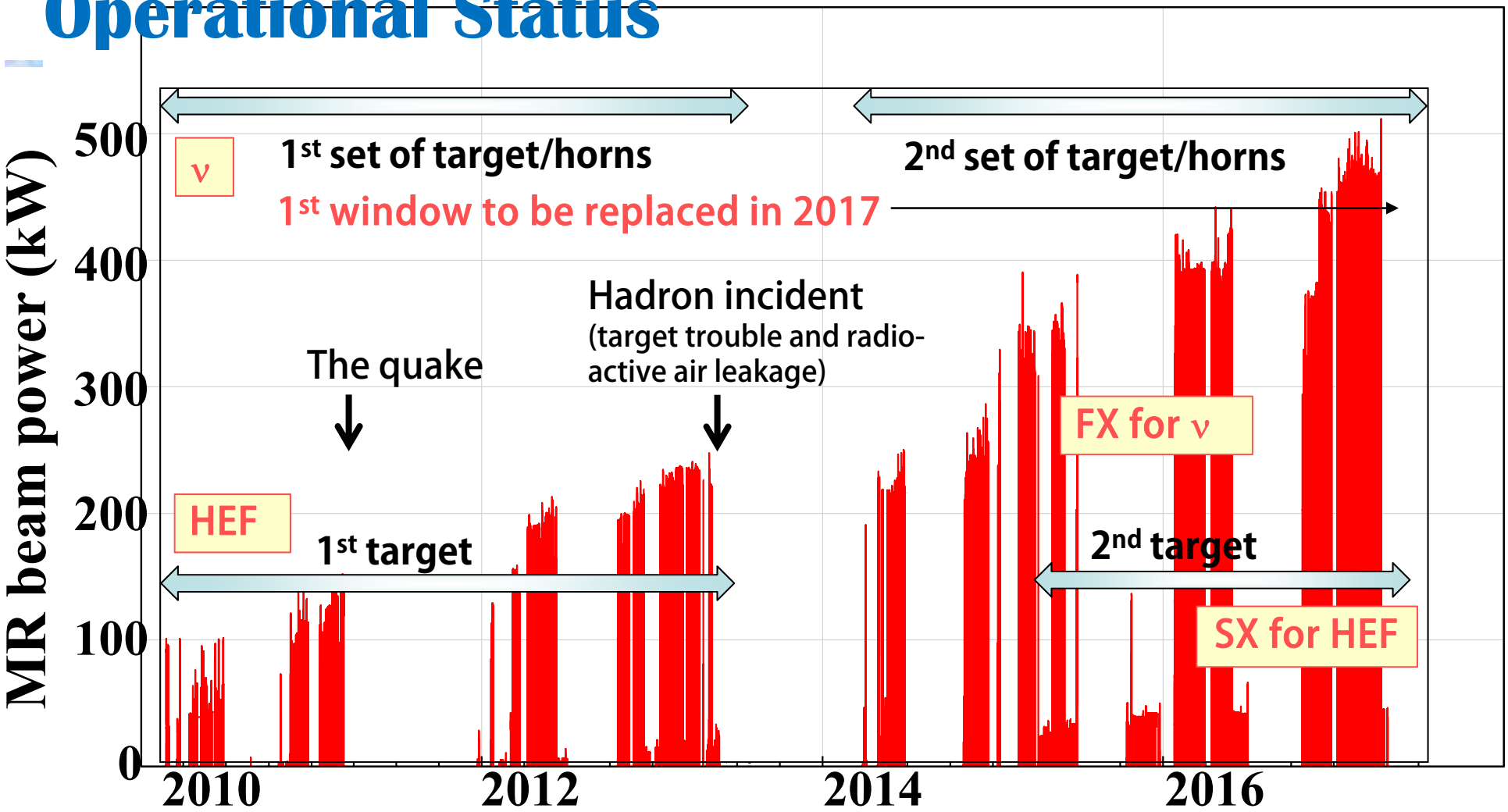




Hadron Hall


K1.8
Strangeness
Nuclear Physics
K1.8BR
Hadron Physics
K Rare Decay
(CP violation)
KL
T1 Target
High Momentum
Beamline
Hadron Mass Shift
COMET Beamline
mu-e Conversion Search

Operational Status



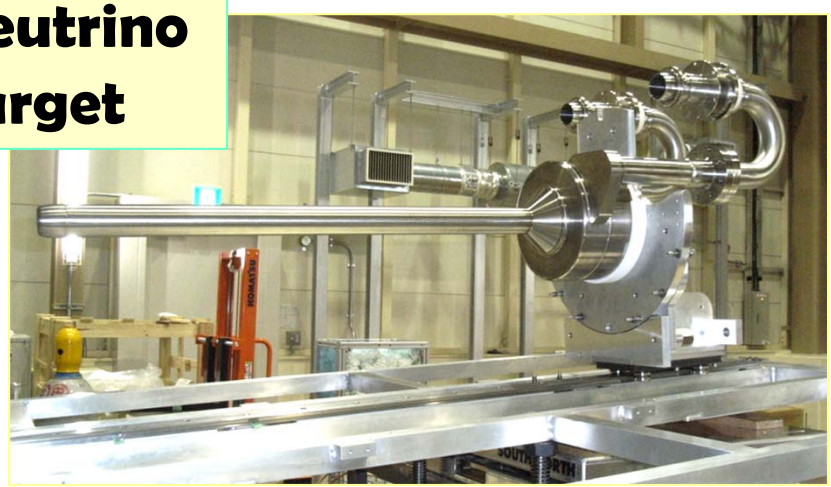
- Max. delivered power:

World record of FX'd # of protons from synchrotron

  - Fast eXtraction to Neutrino 470kW (2.4×10^{14}ppp / 2.48s)
  - Slow eXtraction to HEF 44kW (5.1×10^{13}ppp / 5.52s)

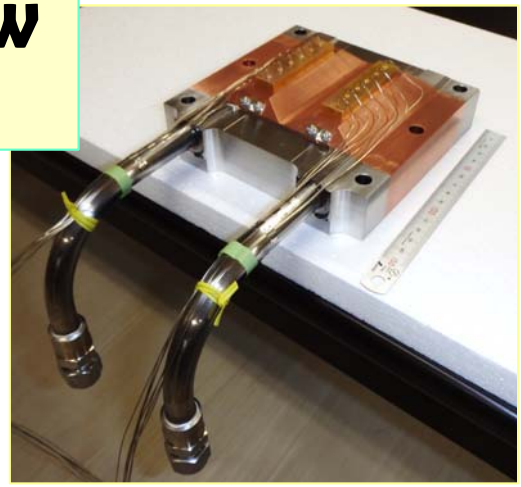
Beam Parameters in Operation

neutrino target



- Helium Cooled IG430U single rod in 64Ti tube/window, ~900mmL
- 30 GeV, Fx 8b in 4.2us
- 2.4×10^{14} ppp (→ 3.2×10^{14} ppp)
- 2.48sec (→ 1.16sec)
- 470kW (→ 1.3MW)
- Beam sigma = 4.2mm
- Minor modifications for >1.3MW

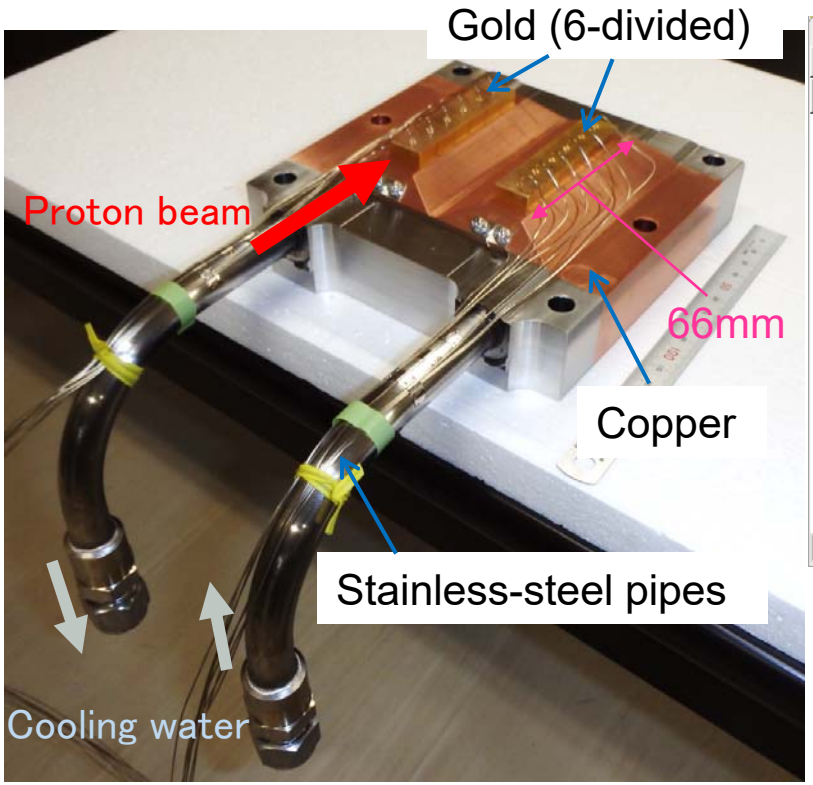
HEF 50kW target

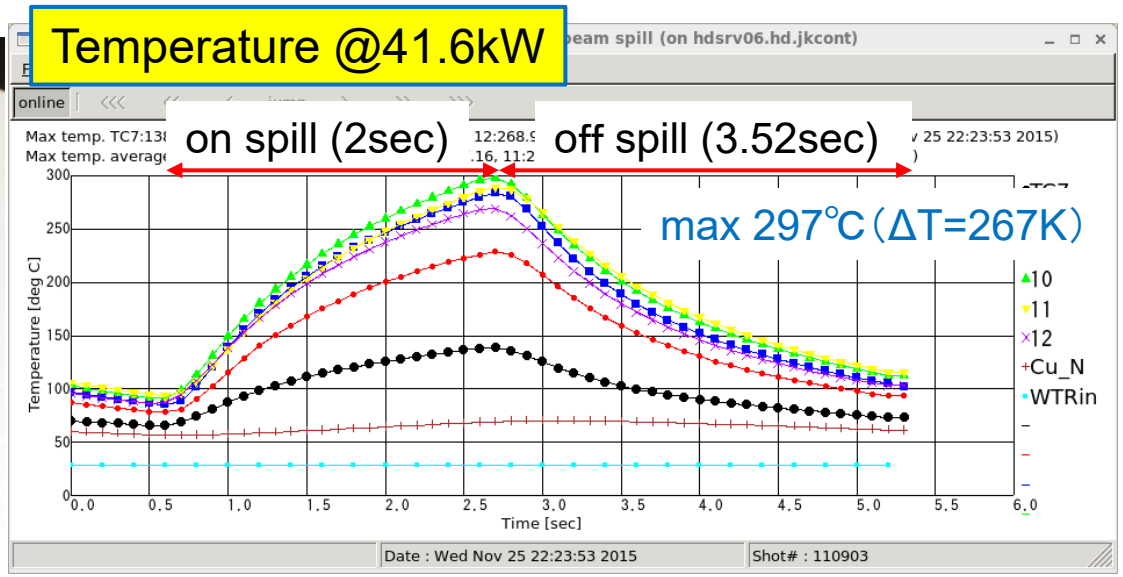


- Water cooled 6 gold pieces bonded on copper, ~66mmL
- 30 GeV, Sx DC (debunched)
- 5×10^{13} ppp
- 5.52sec (on spill 2 sec)
- 44.4kW
- Beam sigma=(2.5mm,1.0mm)
- Upgrade to directly cooled rotating target for >100kW

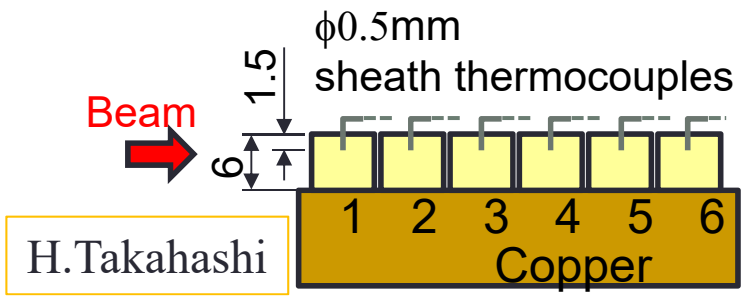
HADRON TARGET

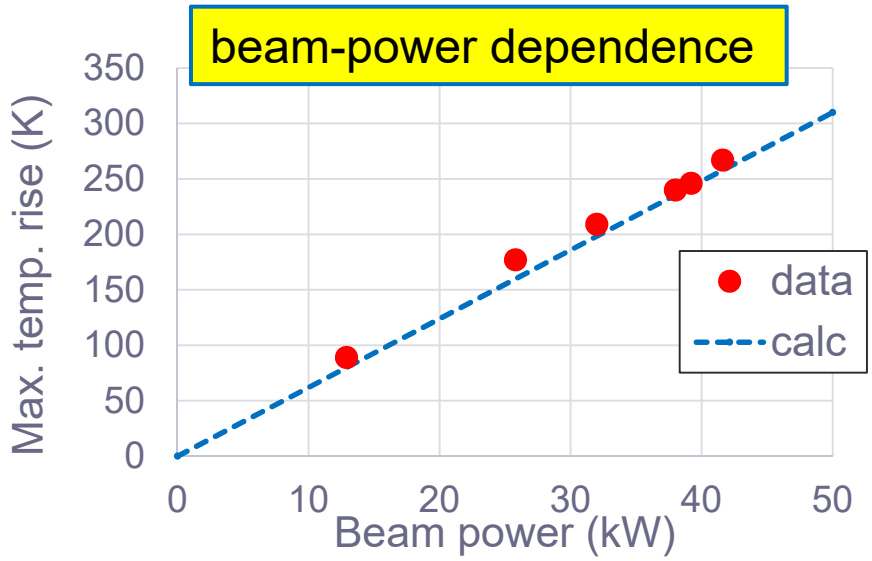
Current Production Target





Temperature of each gold piece was measured with thermocouples every 100ms





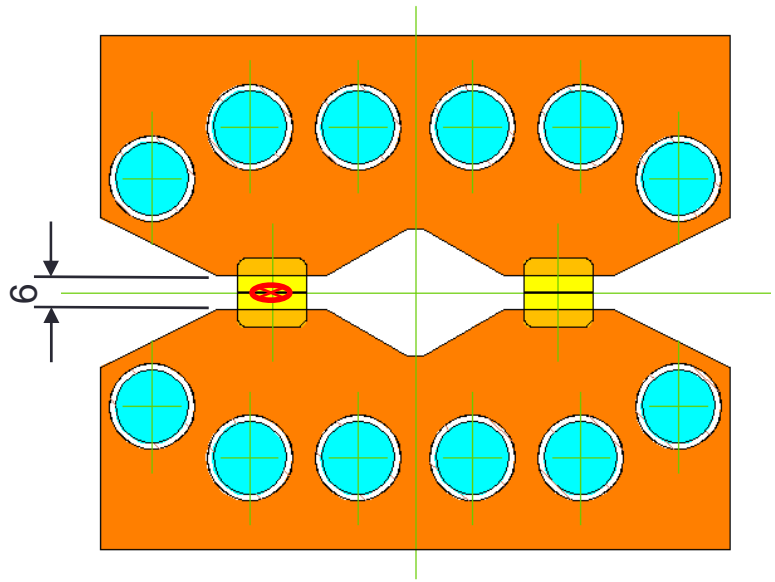
Measured temperature was in good agreement with calculation

Next indirectly water-cooled fixed target

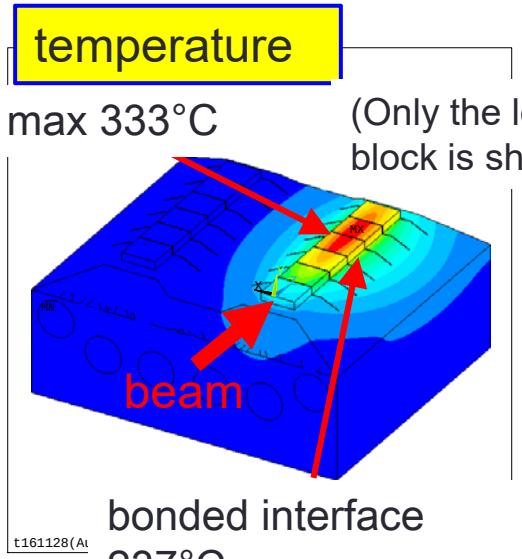
- Gold target with copper cooling block is turned over and stacked on another gold target.
- Each of the gold targets has almost same structure as current target.
- Size of gold is optimized for secondary-beam yield and cooling efficiency.
- ~80 kW proton beam can be accepted.
- Fabrication process is already established.

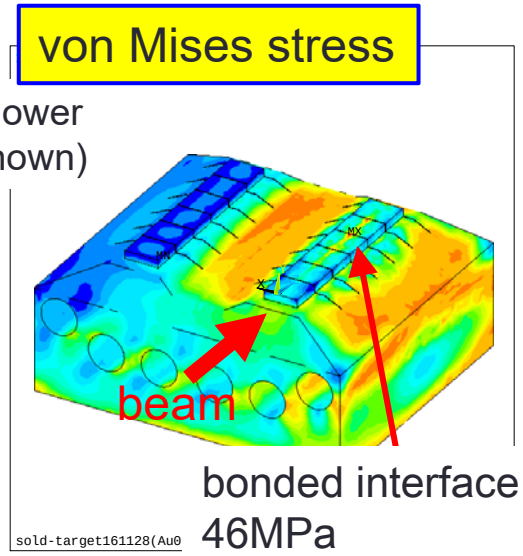
➡ Ready to manufacture

Results of thermal analysis (80kW, 5.52s cycle)



View from upstream





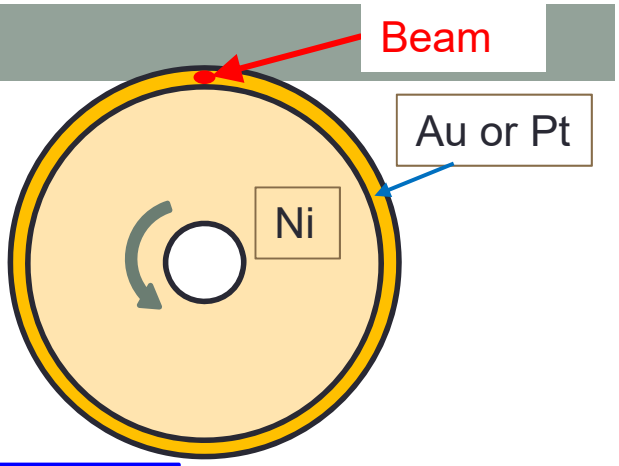
Design margin: 2.7

vertical expansion: max 0.10mm

H.Takahashi

Directly cooled rotating target

- "Euro Coin" target
  - nickel disks with gold or platinum edge
- Water cooled or He-gas cooled
- Several R&Ds are in progress



Results of thermal analysis (Au, 150kW, 5.52s cycle)

temperature

von Mises stress

max 72°C
(ΔT=42K)

beam

beam

bonded interface
6.3MPa

water cooled

clean! (small amount of NOx, H gas, and tritium generation)

beam

beam

thermal stress is considerably smaller than that of indirectly cooled target

He gas cooled

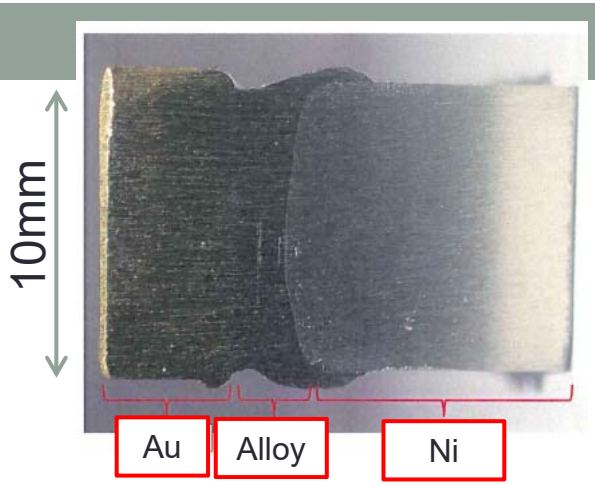
bonded interface
15MPa

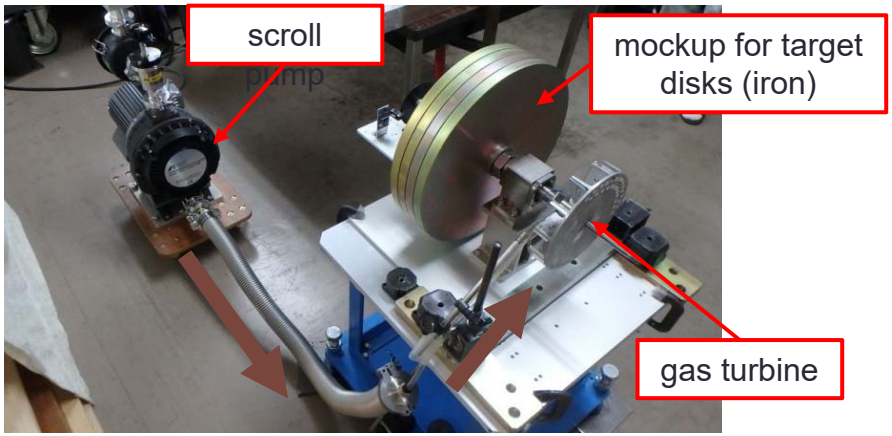
H.Takahashi

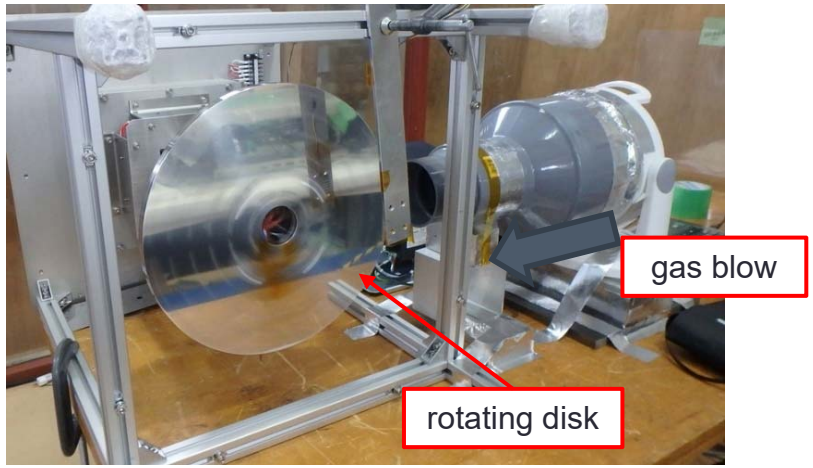
R&Ds for “Euro Coin” Target

- Fabrication process of “Euro Coin”
  - Forming test of thick curved Pt plate
  - Bonding test of Au-Ni and Pt-Ni
- Rotation with gas turbine
  - Simple rotation test using exhaust of scroll pump
- Efficiency of He-gas cooling
  - Efficiency measurement using test bench

Results of EBW test for Au-Ni





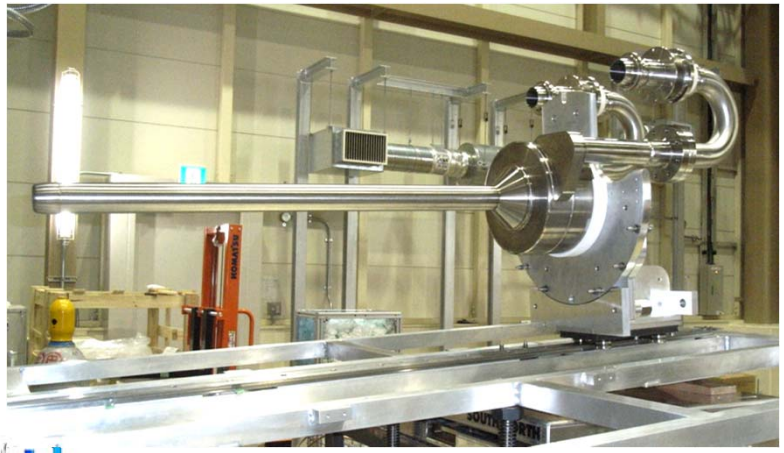


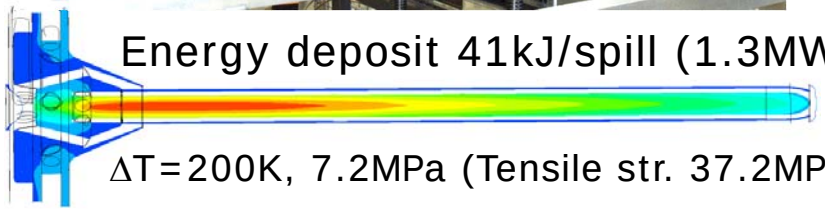
- **How to fabricate the “Euro-coin” disc (Au/Pt&Ni bond) ?**
- **Is the efficiency of Helium gas cooling enough and OK ?**
- **Rotation by He gas turbine ? How to control, Bearing ?**
- **How to measure temperature ?**

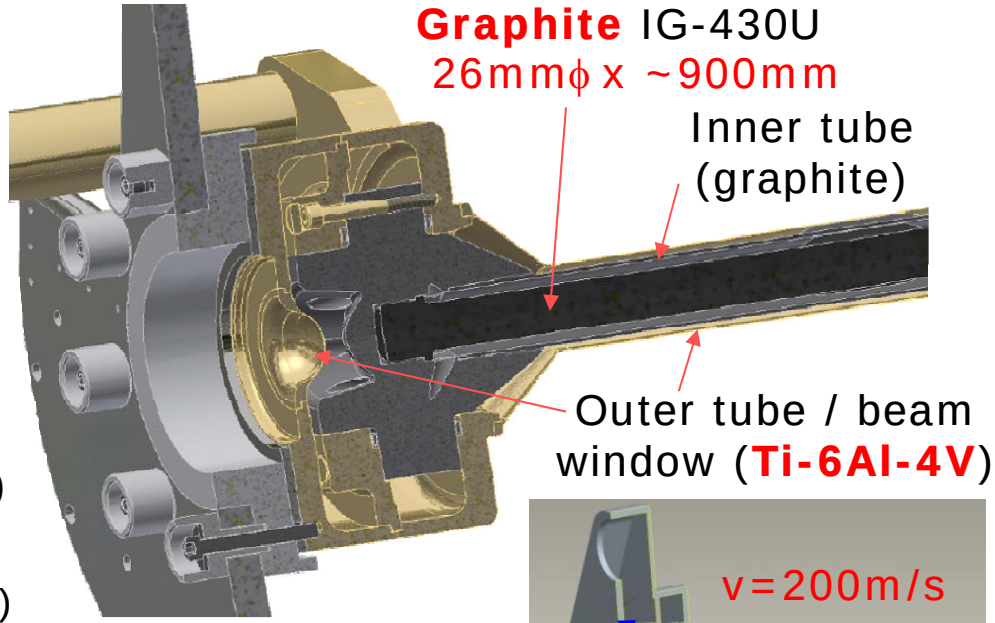
H.Takahashi

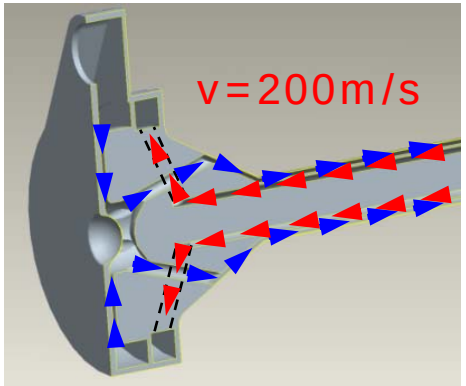
NEUTRINO TARGET & WINDOW

Neutrino Target









	0.75 MW	1.3 MW
Helium pressure	1.6 bar	**5 bar**
Pressure drop	0.83 bar	0.88 bar
Helium mass flow	32 g/s	**60 g/s**
Heat load	23.5 kW	40.8 kW
US window temp	105 ° C	157 ° C
DS window tem	120° C	130° C
Graphite Max. temp.	736° C	**909° C**

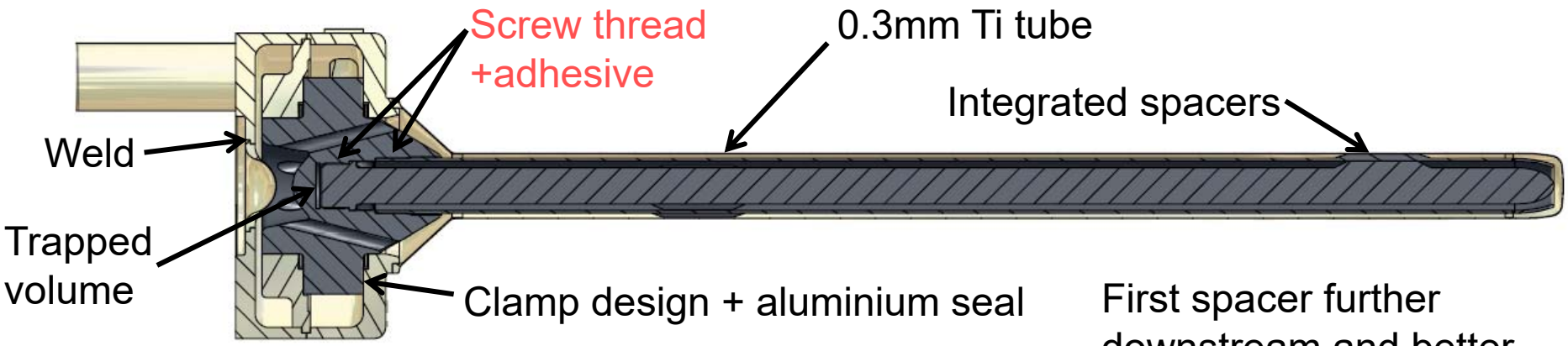
Lifetime 5years under 100ppm

- High Temperature：Oxidization of graphite will be the limiting factor on target lifetime (assuming Ti beam window survives)
- SiC-coated Graphite ?

→ S.Makimura in Session 2

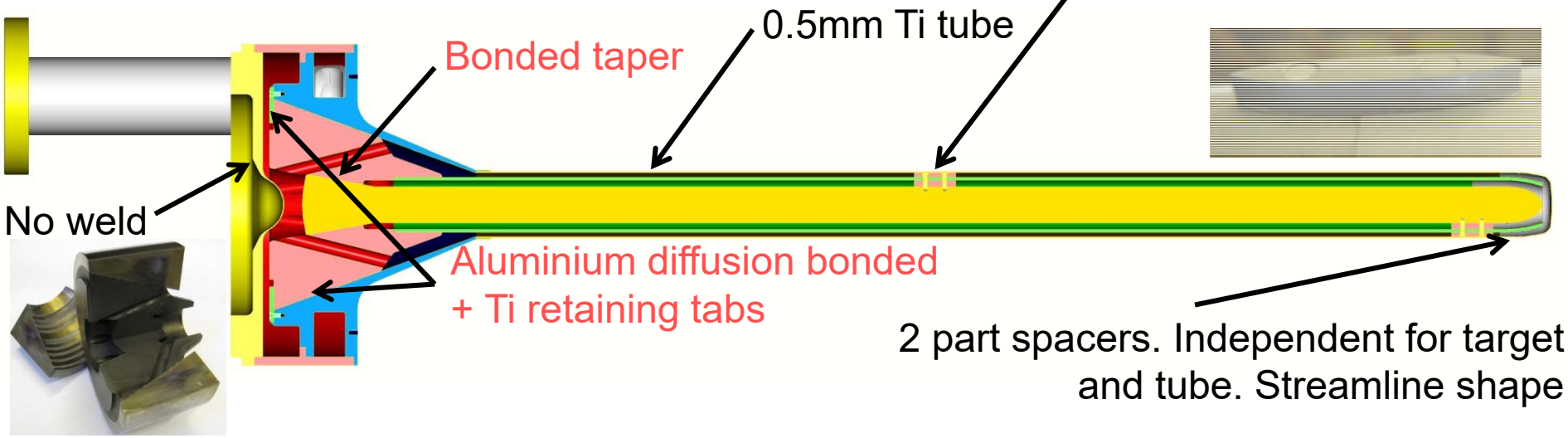
Ver.1&2 Target Assembly

Ver.1 / 1a (in use):



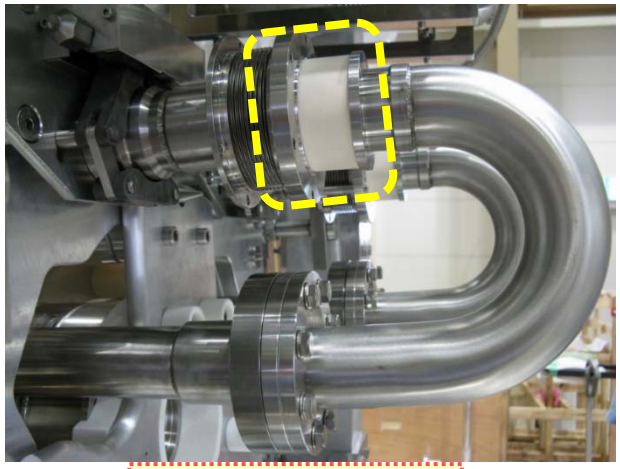
First spacer further downstream and better fit than Ver.1 target

Ver.2:

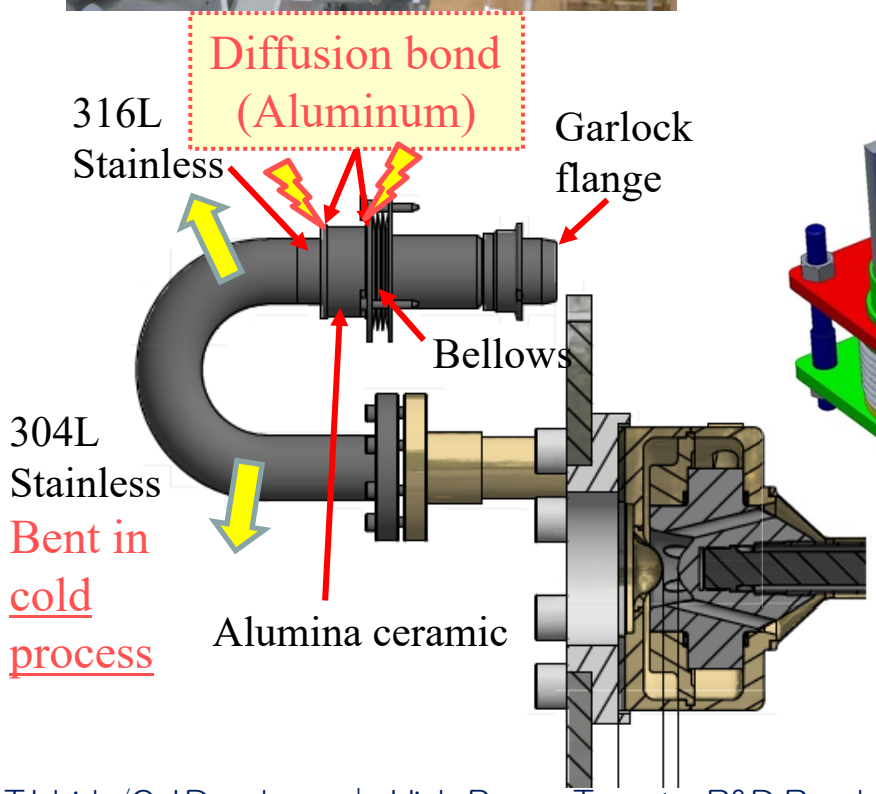


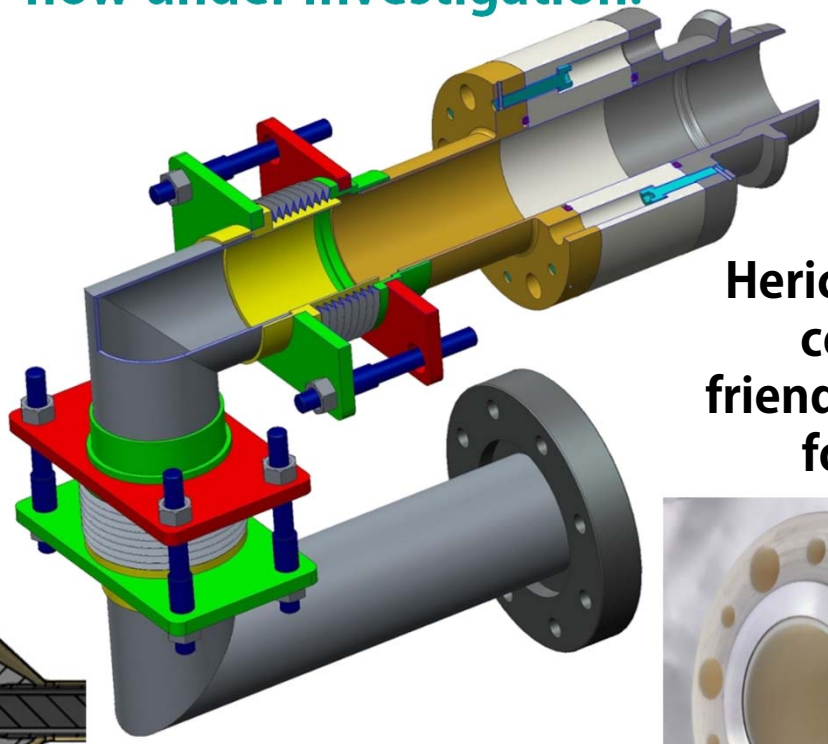
2 part spacers. Independent for target and tube. Streamline shape

Leak at Helium Outlet Pipe (2015)

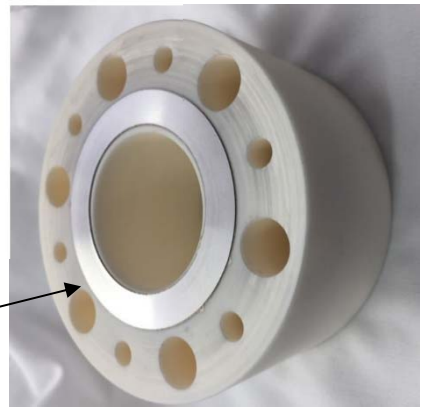


- Diffusion bonding of ceramic may not be enough reliable → bolted joint with helicoflex seal now under investigation.



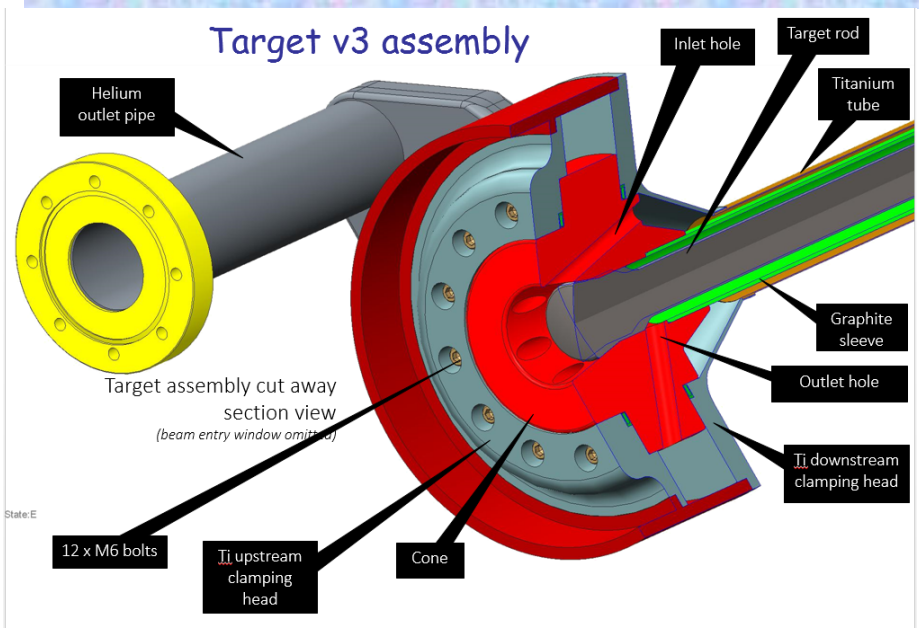


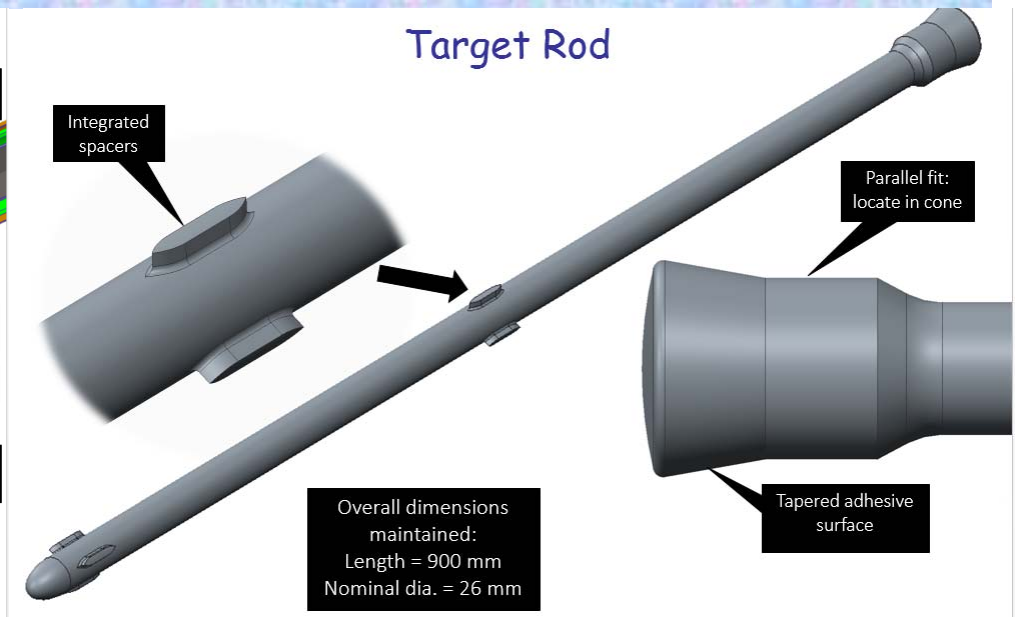
Hericoflex with ceramic not friendly enough for He seal..

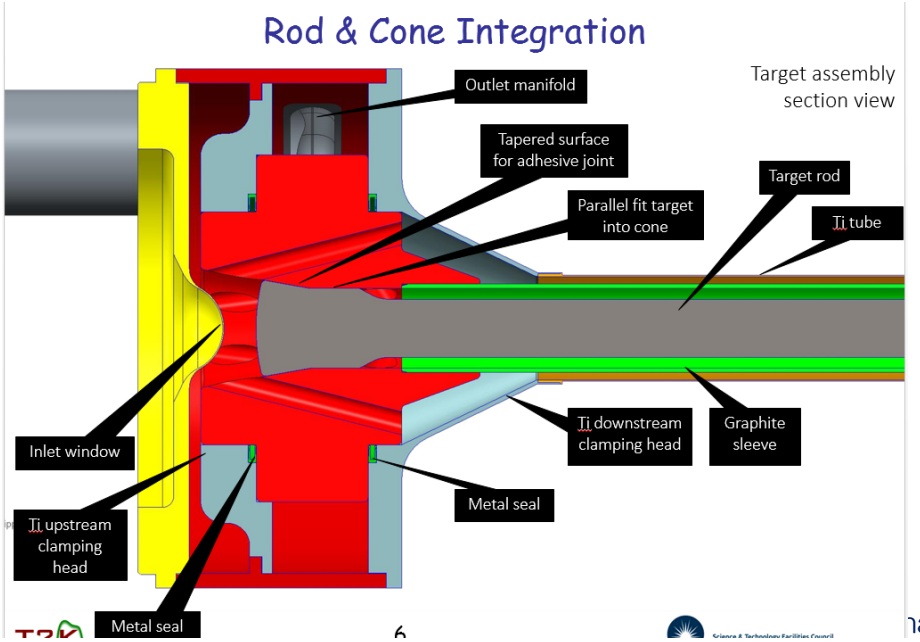


Thin Gr1 foil brazed/machined

Version-3 Target Assembly



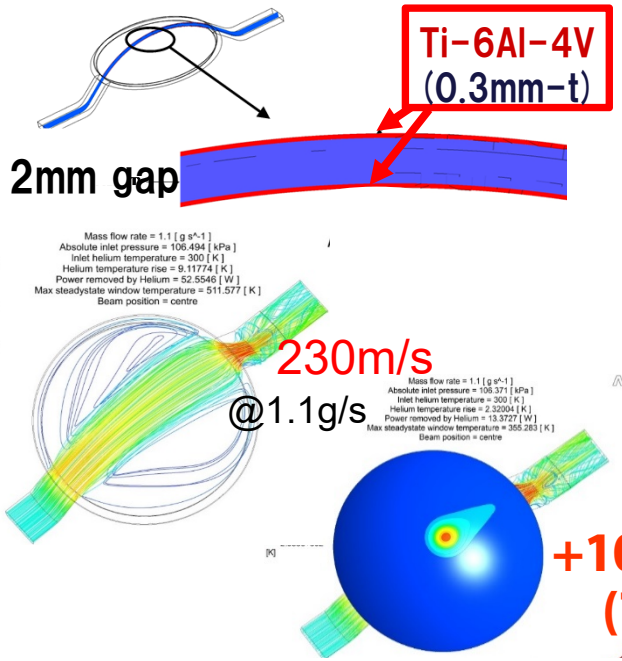




- Integrated spacers
- Target rod locates in cone by parallel fit
- Widened central bore of cone
- Bolted design with metal seals (like v1 and v1a)
- No diffusion bond as in target v2 (current spare)
- Thicker Ti shell / window for high pressure operation

Neutrino Beam Window

- Periodic thermal stress wave (~250 MPa) caused by the intense proton beam penetration
- 750kW operation will cause radiation damage of ~1DPA/year, whereas significant irradiation hardening and loss of ductility reported with 0.3DPA and no higher DPA data exist
- No known data exists on high cycle fatigue (10^7/year) of the irradiated material

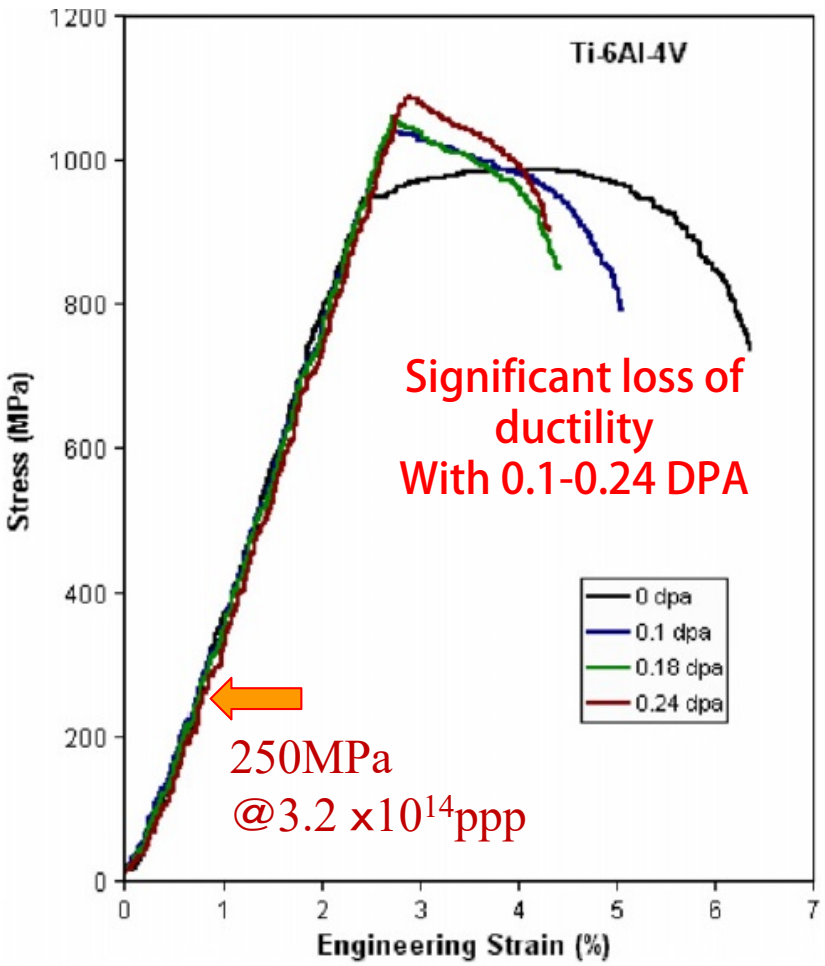


Beam Power	PPP	Rep. cycle	POT / 100 days
470kW (achieved)	2.4×10^{14}	2.48 sec	(0.8×10^{21})
750kW (proposed)	2.0×10^{14}	1.3 sec	1.3×10^{21}
750kW [original plan]	3.3×10^{14}	2.1 sec	1.3×10^{21}
1.3 MW (proposed)	3.2×10^{14}	1.16 sec	2.4×10^{21}

designed

~1DPA/yr (MARS)

Radiation damage effect on Ti-6Al-4V

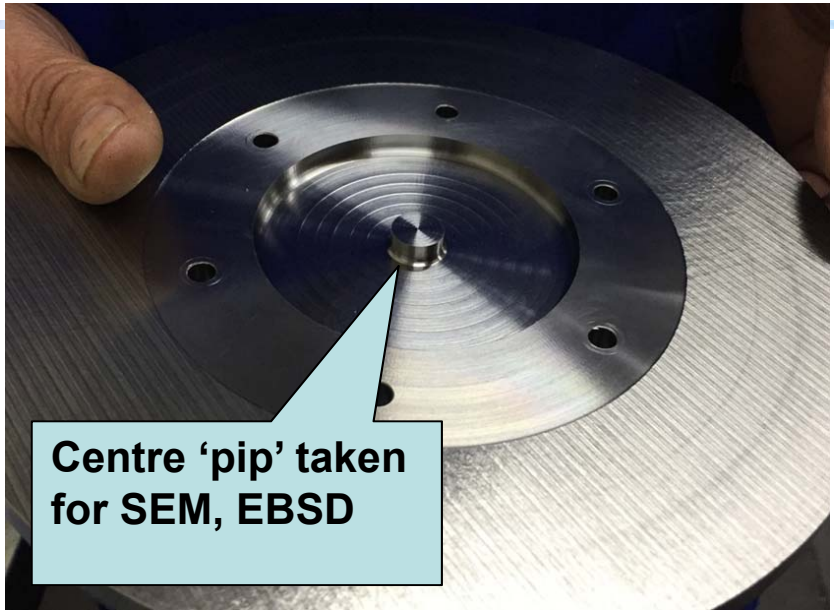


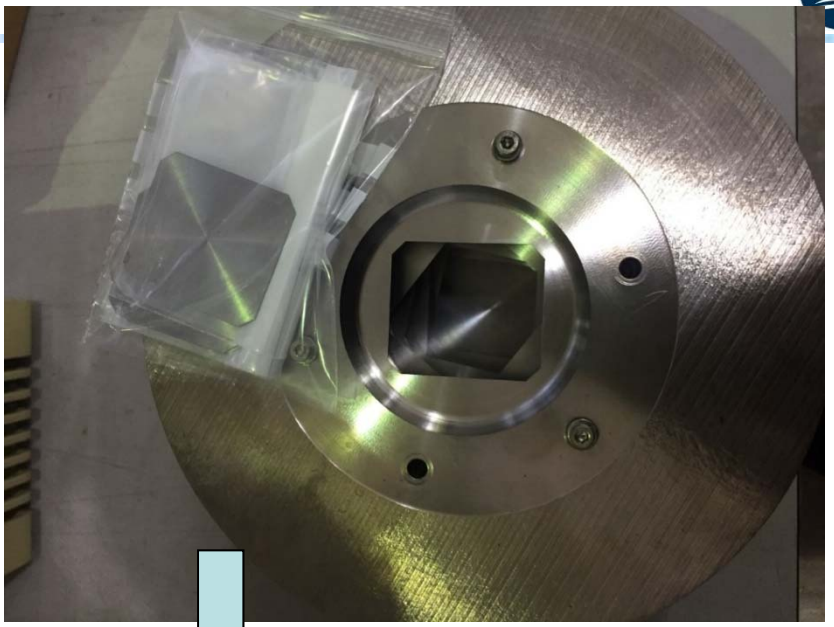
N.Simos et al. J.Nucl.Mat. 377 (2008) 41

- The 1st beam-window still in service (to be replaced in 2017)
- Thermal stress for 1.3MW beam (~250MPa) is lower than the elastic limit
- POT until 2017： ~2x10^21pot
  - Probably nearly 2 DPA
  - Close to the damage of 1.3MW×1yr (2.4x10^21pot)
- Existing data only up to 0.24dpa:
- Study of radiation damage effect in a few DPA region is critical
- New BLIP irradiation run up to 0.7DPA
  - 1st ever high-cycle fatigue data
  - Other Ti alloy (Gr-9: Ti-3Al-2.5V)

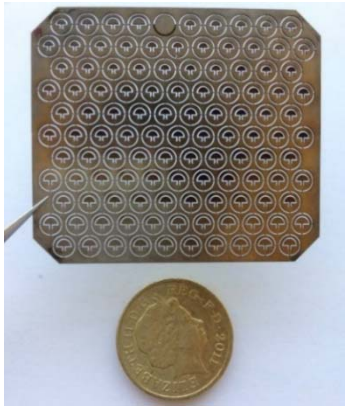
→ K.Ammigan in Session-2

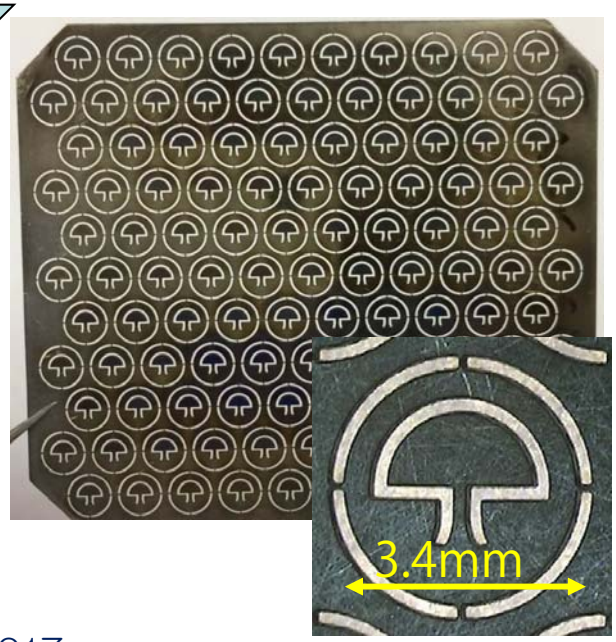
Meso-scale sample from ver.2 window





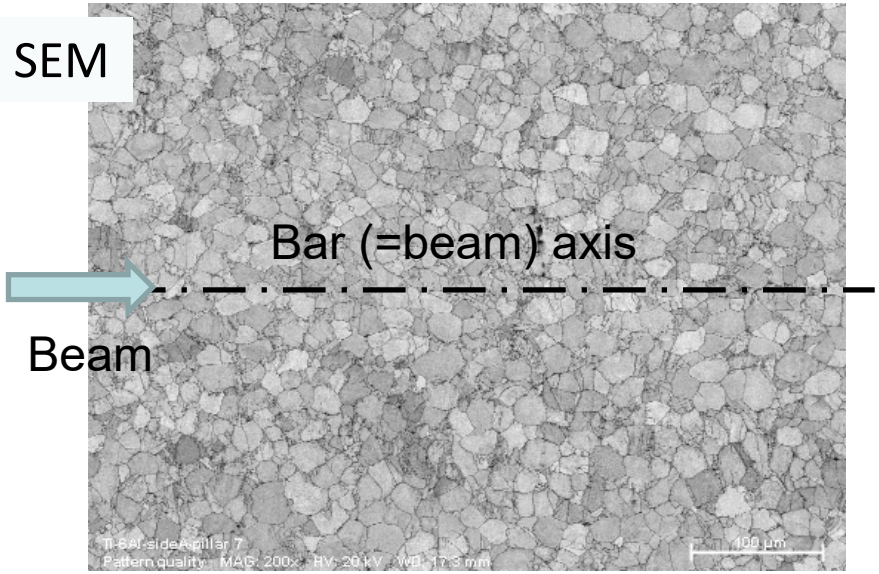
- Preparation of meso-scale fatigue samples
- 6 x 0.3 mm thick discs machined from same 8" Ti-6Al-4V bar purchased for next T2K window domes
- 2 x sample foils polished to 0.25 mm and laser cut using very fine scanning laser





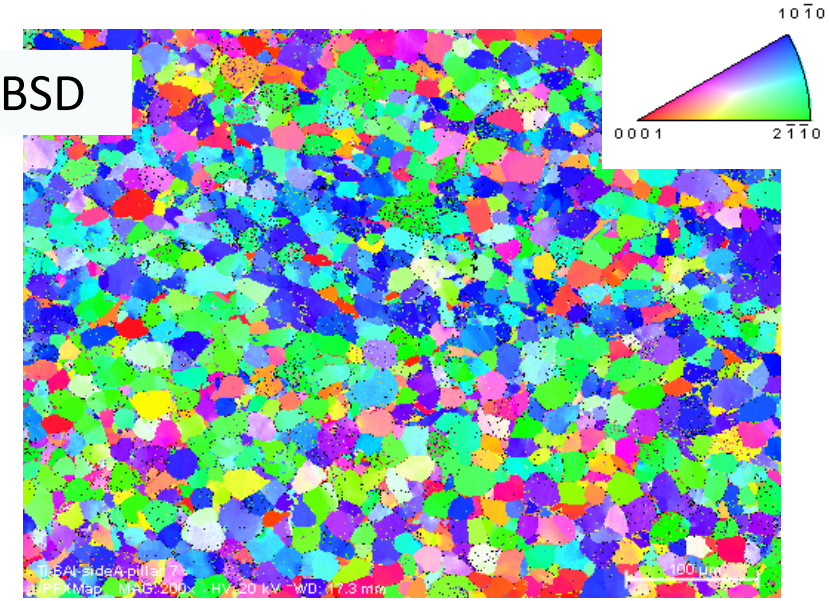
Characterisation of next beam window material (c/o Oxford uni)

SEM



Quality map

EBSD

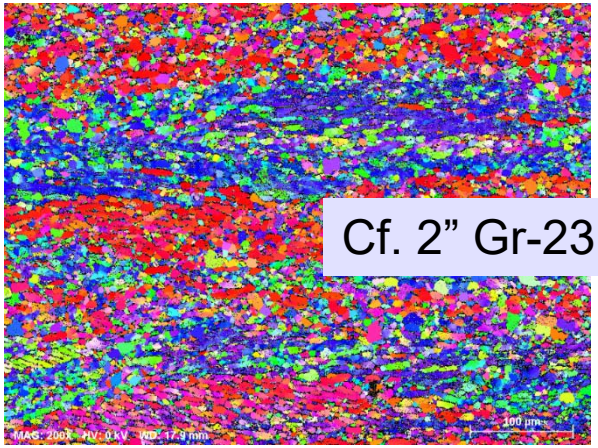


IPFX

0.4 mm

0 mm

Sample taken from centreline of same 200 mm diameter bar to be used for next beam window AND used in meso-scale fatigue samples Looks like well distributed, equiaxed grains, fine grained without texture in through-thickness direction.



Cf. 2” Gr-23 Plate

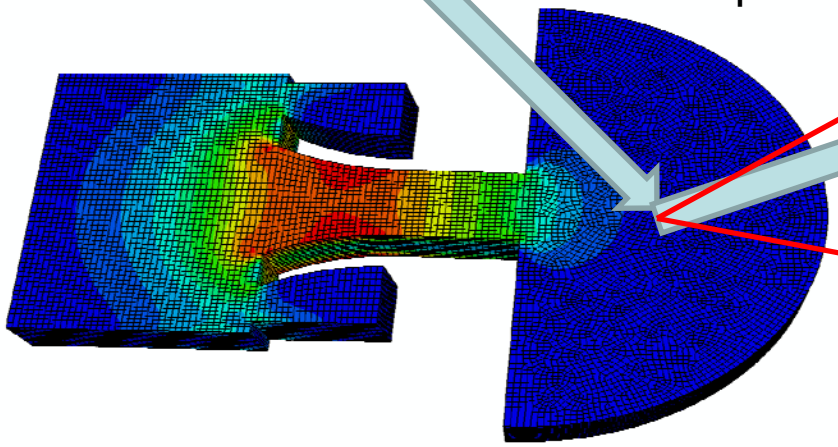
Measurement of deflection during resonant vibration (Oxford Univ. materials)

Need to operate *near* but not *on* resonant frequency (c.20kHz) to generate stress range
-> need to measure amplitude

Input laser beam

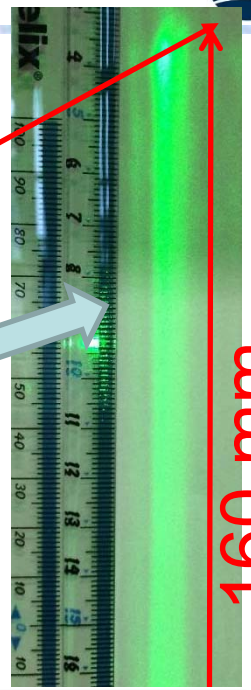
Specular Reflection

Movement of beam due to deflection

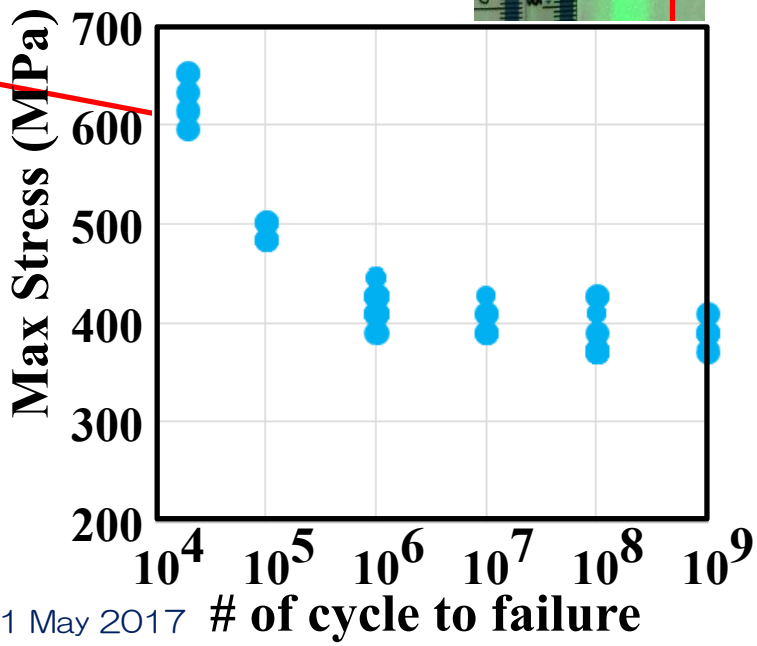


~3.5 m

~0.65°



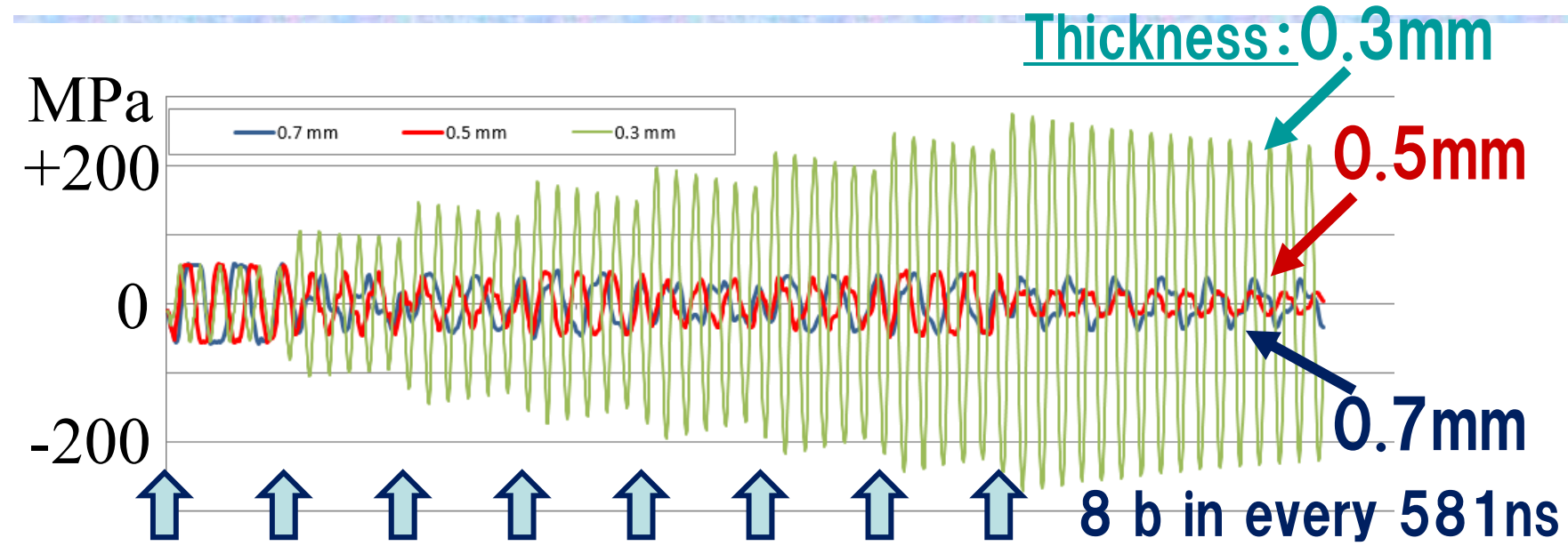
160 mm

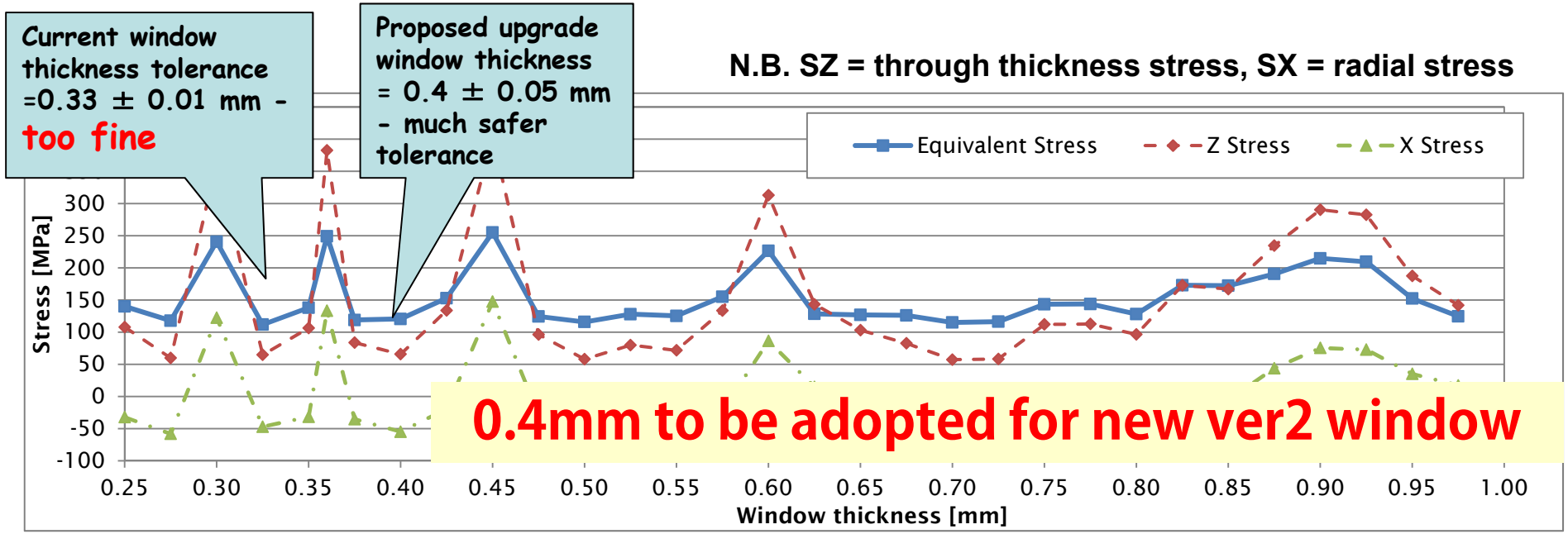


Tresca (maximum shear) stress

Need to reproduce test equipment at Culham lab. for active samples testing

Stress Wave Analysis for Ti window





Classification of Ti-alloys

組　成	熱処理	引張性質		
		引張強さ (MPa)	耐力 (MPa)	伸び (%)
純チタン(α)				
JIS 1 種	A	270～410	≧165	≧27
JIS 2 種	A	340～510	≧215	≧23
JIS 3 種	A	480～620	≧345	≧18
JIS 4 種	A	550～750	≧485	≧15
α 合金				
Ti-5 Al-2.5 Sn	A	862	804	16
α リッチ α-β 合金				
Ti-8 Al-1 Mo-1 V	A	1 000	951	15
Ti-6 Al-2 Sn-4 Zr-2 Mo	A	980	892	15
α-β 合金				
Ti-3 Al-2.5 V	A	686	588	20
Ti-6 Al-4 V	A	980	921	14
	STA	1 170	1 100	10
Ti-6 Al-6 V-2 Sn	A	1 060	990	14
	STA	1 270	1 170	10
Ti-6 Al-2 Sn-4 Zr-6 Mo	STA	1 270	1 180	10
Ti-10 V-2 Fe-3 Al	STA	1 270	1 200	10
β 合金				
Ti-13 V-11 Cr-3 Al	STA	1 220	1 170	8
Ti-3 Al-8 V-6 Cr-4 Mo-4 Zr	STA	1 440	1 370	7
Ti-11.5 Mo-6 Zr-4.5 Sn	STA	1 380	1 310	11
Ti-15 Mo-5 Zr-3 Al	STA	1 470	1 450	13
Ti-15 V-3 Cr-3 Al-3 Sn	STA	1 230	1 110	10

A：焼きなまし／STA：溶体化時効

Pure Ti(α)

Gr6(α)

BLIP

Gr9(α+β)

Gr5(α+β)

Gr23(α+β)

(β)

OTR

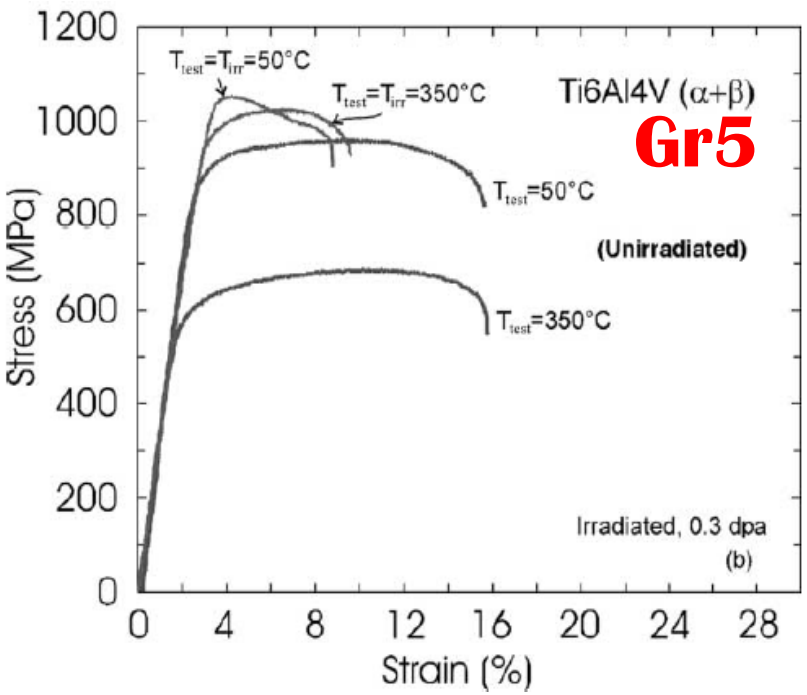
specific gravity
Heat-treatability
Plasticity/machinability
Strain rate sensitivity

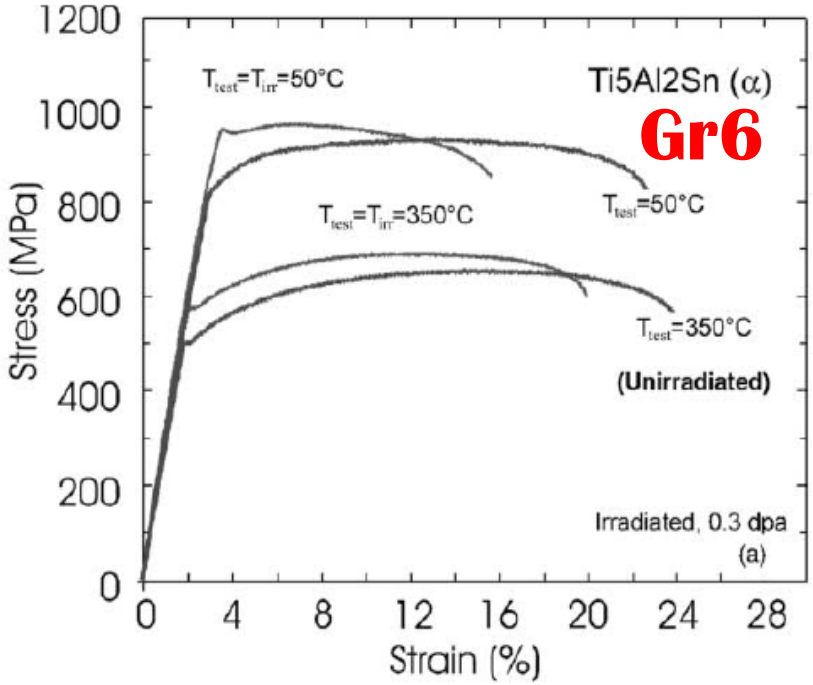
Creep strength
Young's modulus
Oxidation resistance

- **Gr23** : Improved ductility and fracture toughness with some reduction in strength
- **Gr9:** α-like α β-alloy, compromise of pure&Gr5
- **Ti-15-3-3-3:** metastable β-alloy, Coil producible by hot & cold rolling

Neutron Irradiation Data (0.3DPA)

S.Tahtinen et al. J. Nucl.Mat. 307-311 (2002) 416





- Is alpha-alloy (HCP) better for radiation hardening ?
- Gr-9 Ti-3Al-2.5V α-like α β-alloy will be in BLIP irradiation test (→ Ammigan in session-2)

Summary

- For future >100 kW operation of Hadron facility, upgrade to rotational target directory cooled by Helium (or water) is under development.
  - ✓ "Euro Coin" target: nickel disks with gold or platinum edge
- Neutrino target and window : designed with 3.3 x 10^{14} ppp, hopefully applicable for coming 750kW → 1.3MW operation with minor upgrades
- Oxidization of graphite will determine the life of target. More cooling by higher mass-flow rate – pressure (5bar) under study
  - ✓ How to suppress oxidation of graphite ? (SiC-coating or better way ?)
  - ✓ Can (brittle) target beam window survive with high pressure ?
- Study on radiation damage effect of Titanium alloy with a few DPA region is critical to determine service life of neutrino window applications
  - ✓ Ver.1 window (Ti-6Al-4V Gr-5 bar) survives for >2x10^{21} pot, close to 2DPA (MARS)
  - ✓ BLIP irradiation run provides precious data (fatigue/tensile) for 0.7DPA
  - ✓ Comprehensive understanding of radiation damage effect on different type of alloys and different heat treatments are desirable.

Mid-term plan of MR (Revised in Jan. 2017)

JFY	2015	2016	2017	2018	2019	2020	2021	2022
		New buildings		HD Target	Long shutdown			
FX power [kW]	390	470	480-500	> 500	700	800	900	1000
SX power [kW]	42	42	50	50-60	60-80	80	80-100	100
Cycle time of main magnet PS New magnet PS	2.48 s	Mass production installation/test		2.48 s	1.3 s	1.3 s	1.3 s	1.3 s
High gradient rf system 2nd harmonic rf system	Installation	Manufacture, installation/test						
Ring collimators	Add.collimators (2 kW)				Add.colli. (3.5kW)			
Injection system FX system	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, FX septa manufacture /test							
SX collimator / Local shields					Local shields			
Ti ducts and SX devices with Ti chamber			ESS					

High repetition rate operation to realize >1MW (FX)